Fisheries and Oceans Science | Pêches et Océans Sciences

C S A S | **S C É S**

Canadian Stock Assessment Secretariat | **Secrétariat canadien pour l'évaluation des stocks**

Research Document 2000/059 | **Document de recherche 2000/059**

Not to be cited without permission of the authors [1]

Ne pas citer sans autorisation des auteurs [1]

Overview of Meteorological and Sea Ice Conditions off Eastern Canada during 1999

K.F. Drinkwater, R.G. Pettipas and W.M. Petrie

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
Box 1006, Dartmouth, N.S. B2Y 4A2

[1] This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

[1] La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at: Ce document est disponible sur l'Internet à:
http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883
Ottawa, 2000

Canada

ABSTRACT

A review of meteorological and sea ice conditions off eastern Canada during 1999 is presented. Annual mean air temperatures throughout most of the northwest Atlantic warmed relative to 1998 setting record high values in the region from southern Labrador to Cape Cod. The maximum air temperature anomalies and the largest increases relative to 1998 were in the Gulf of St. Lawrence, on the Scotian Shelf and over eastern Newfoundland. Seasonally, air temperatures in most areas of the northwest Atlantic were above normal in 10 out of the 12 months of 1999. The only exception to the warm air temperatures was on the West Greenland side of the Labrador Sea. The North Atlantic Oscillation (NAO) index for 1999 was well above normal, reversing the trend of below normal and near normal values of the previous three years. This indicates that the large-scale atmospheric circulation, including the Icelandic Low and the Azores High, intensified in 1999. The NAO index in 1999 was similar to levels obtained in the cold period of the early 1990s. Sea ice on the southern Labrador and Newfoundland shelves generally appeared on schedule but left early, resulting in a shorter duration of ice than usual. The ice coverage in these areas during 1999 was lower than average but similar to 1998. The number of icebergs reaching the Grand Banks in 1999 was only 22, well down from the 1384 icebergs observed in 1998. The small number of bergs in 1999 is consistent with the reduced ice cover later in the season and the generally warmer-than-normal air temperatures. In the Gulf of St. Lawrence, the sea ice also appeared on schedule and although there was a tendency to disappear earlier-than-normal, there were still significant portions of the Gulf where the date of last presence was later than usual. Little to no ice reached the Scotian Shelf proper and the areal coverage of ice in the Sydney Bight area off eastern Cape Breton was much less-than- normal.

RÉSUMÉ

Les conditions météorologiques et les conditions des glaces de mer au large de la côte est du Canada en 1999 sont passées en revue. Les températures annuelles moyennes de l’air dans presque tout le nord-ouest de l’Atlantique ont augmenté par rapport à 1998, établissant de nouveaux records entre le sud du Labrador et le cap Cod. Les anomalies maximales de la température de l’air et les plus fortes augmentations par rapport à 1998 ont été observées dans le golfe du Saint-Laurent et les régions du plateau néo-écossais et de l’est de Terre-Neuve. Sur le plan saisonnier, les températures de l’air dans la majeure partie du nord-ouest de l’Atlantique ont été supérieures à la normale pour 10 des 12 mois de l’année 1999. Seule la partie de la mer du Labrador située à l’ouest du Groënland n’a pas connu de températures chaudes. L’indice de l’oscillation nord-atlantique (ONA) pour 1999 a nettement dépassé la normale et inversé la tendance des trois dernières années qui affichait des valeurs inférieures ou près de la normale. Cette augmentation indique que la circulation atmosphérique à grande échelle, y compris la dépression d’Islande et l’anticyclone des Açores, s’est intensifiée. L’indice de 1999 est similaire aux valeurs obtenues durant la période froide du début des années 1990. Sur les plates-formes du sud du Labrador et de Terre-Neuve, l’apparition des glaces a généralement suivi le calendrier normal, mais leur disparition a été hâtive. Les glaces ont donc été présentes moins longtemps que d’habitude. En outre, leur couverture dans ces zones a été inférieure à la moyenne de 1999, quoique similaire à 1998. Seulement 22 icebergs ont atteint les Grands Bancs, comparativement à 1 384 l’année précédente. Le nombre plus faible d’icebergs de 1999 concorde avec la moindre couverture des glaces à la fin de la saison et avec les températures de l’air généralement supérieures à la normale. Dans le golfe du Saint-Laurent, l’apparition des glaces de mer a également suivi le calendrier normal et, malgré une tendance à disparaître plus tôt que la normale, leur disparition sur de grandes étendues a été plus tardive que la normale. Peu ou pas de glaces ont atteint le plateau néo-écossais, et la superficie couverte par les glaces dans la zone de Sydney Bight au large du cap Breton a été très inférieure à la normale.

INTRODUCTION

This paper examines the meteorological and sea ice conditions during 1999 off eastern Canada (Fig. 1). Specifically, it discusses air temperature trends, atmospheric sea level pressures and associated winds, sea ice coverage and iceberg drift. It complements the oceanographic reviews of the waters in and around Newfoundland, the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine, which together constitute the annual physical environmental overviews to DFO's Fisheries Oceanography Committee. Environmental conditions are compared with those of the preceding year as well as to the long-term means. The latter comparisons are usually expressed as anomalies, i.e. deviations from their long-term mean, and where the data permit, the latter have been standardized to a 30-yr (1961-90) base period in accordance with the convention of meteorologists and the recommendations of the Northwest Atlantic Fisheries Organization (NAFO). Having a standardized base period allows direct comparison of anomaly trends both between sites and between variables.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

The German Weather Service publishes monthly air temperature anomalies relative to the 1961-90 means for the North Atlantic Ocean in their publication *Die Grosswetterlagen Europas* (Deutscher Wetterdienstes, 1999). Warmer-than-normal temperatures dominated over most of eastern Canada and its coastal waters during 1999 while there were generally cold conditions over the Greenland side of the Labrador Sea (Fig. 2). In January, warm air covered the continental shelves from southern Labrador through to the southern United States, with a maximum positive anomaly (> 3°C) located south of Cape Hatteras. In contrast, over the Labrador Sea and Baffin Bay, air temperatures in January were below normal by upwards of 4°C. Mild conditions continued for the remainder of the winter over the region south of Labrador to the Middle Atlantic Bight with positive anomalies between 2°-3°C during February and 3°-6°C in March. In February, the Labrador Sea was again covered by a colder-than-normal air mass but gave way to warm conditions in March. Temperatures were only slightly above normal over most of the northwest Atlantic in April but by May the pattern of warm air over southern Canada and cold air over portions of the Labrador Sea had returned. In June through September, this same pattern persisted with slight modifications. Only in July, October and November, did the Labrador Shelf and coastal regions experience colder-than-normal conditions. In contrast, the West Greenland side of the Labrador Sea was colder-than-normal throughout the year, with the exception being March. The warmest temperature anomalies were observed in December with values of 6°-8°C over eastern Hudson Bay, Hudson Strait and southern Baffin Island.

Monthly air temperature anomalies for 1998 and 1999 relative to their 1961-90 mean at eight sites in the northwest Atlantic from Godthaab in Greenland to Cape Hatteras on the eastern coast of the United States are shown in Fig. 3 (see Fig. 1 for locations). Data from the Canadian sites were available from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA, 1999). March and April temperatures from Godthaab were estimated using regressions with Egedesminde. The predominance of warmer-than-normal air temperatures over most of eastern Canadian waters during 1999, noted above, is clearly evident (Fig. 3). At Sable Island, all months were above normal, on the Magdalen Islands all months but one (October), and at Cartwright and St. John's all but two (October and

November). Boston and Cape Hatteras had colder-than-normal means in three months. Not only was there a majority of months with above average monthly mean air temperatures, but also the amplitude of the anomalies were high. Anomalies of +3° to 4°C were common. In contrast to these warm conditions, Godthaab temperatures were colder-than-normal for 6 months of year and the amplitude of the anomalies during the warmer-than-normal months was small.

The mean annual air temperature anomalies for 1999 were also calculated at all eight sites. For all sites except Godthaab, the annual anomalies were above normal. The maximum anomaly was recorded on the Magdalen Islands (2.4°C) where it set a new high for the 66-year time series, eclipsing last year's record by 0.9°C. New record highs were also recorded at Sable Island (1999 anomaly of 2.1°C; an 85-year record), St. John's (1.9°C; 126-year record), and Cartwright (1.9°C; 65-year record). The time series of the annual anomalies are shown in Fig. 4. The high air temperature anomalies in 1999 are clearly evident. At St. John's, the Magdalen Islands and Sable Island the annual anomaly rose above 1998 values by approximately 1°C and at Cartwright by 0.7°C. At the remaining sites they were similar to 1998 except at Godthaab where the anomaly declined by 1.2°C. Note that the interannual variability in air temperatures since 1960 at Godthaab, Iqaluit, Cartwright, and, to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with minima in the early 1970s, early to mid-1980s and the early 1990s, suggesting a quasi-decadal period. Indeed, the recent rise in temperature at most of these sites is consistent with a continuation of this near decadal pattern. Unlike previous years, monthly temperature anomalies at the Magdalen Islands and Sable Island were generally of higher amplitude than at the more northern sites. These two sites also contain quasi-decadal fluctuations with minima in the early 1970s (both sites), the mid-1980s (Sable Island only) and in the 1990s (Magdalen Islands only). Air temperatures at Boston and Cape Hatteras have generally been out of phase with the temperature fluctuations in the Labrador region. Thus, for example, when the temperatures were very cold in Labrador during the early 1990s, they were relatively warm along the US seaboard (Fig. 5). Also note that all sites where data are available, cold conditions (relative to the 1961-90 mean) existed throughout the late 1800s and early 1990s. Temperatures rose to above normal values between the 1910s and 1950s, the actual timing being site-dependent.

Sea Surface Air Pressures

Climatic conditions in the Labrador Sea area are closely linked to the large-scale pressure patterns and atmospheric circulation. Monthly mean sea-surface pressures over the North Atlantic are published in *Die Grosswetterlagen Europas*. The long-term seasonal mean pressure patterns are dominated by the Icelandic Low centred between Greenland and Iceland and the Bermuda-Azores High centred between Florida and northern Africa (Thompson and Hazen, 1983). The strengths of the Low and High vary seasonally from a winter maximum to a summer minimum. Seasonal anomalies of the sea-surface pressure for 1999, relative to the 1961-90 means, are shown in Fig. 5. Winter includes December 1998 to February 1999, spring is March to May, summer is June to August and autumn is September to November.

In winter, a strong dipole pattern was established with negative air pressure anomalies in the northern North Atlantic and with positive anomalies over most of the southern North Atlantic. The largest negative anomalies (below -7 mb) were located northeast of Iceland and the largest positive anomalies (>5 mb) were centred over the Azores. These high anomalies extended across the entire width of the Atlantic Ocean. This pattern indicates a strengthening of the atmospheric circulation with an intensification of both the Iceland Low and the Azores High. Strong westerly winds across the northern North Atlantic accompany this pressure pattern with the maximum wind anomalies over western Europe. Over the Labrador Sea the pressure field implied slightly stronger-than-normal northwesterly winds, which are consistent with the colder-than-normal air temperatures during the winter over West Greenland. Southeastern Canada came under the influence of the Azores High producing southerly winds that carried relatively warm air into the region. The intensification of the pressure systems in 1999 is similar to what occurred in the first half of the 1990s. However, the spatial patterns differ in that the center of the large amplitude changes was shifted further eastward in 1999 and the influence of the High extended into southeastern Canadian waters.

In the spring of 1999, a relatively strong negative pressure anomaly (> 2 mb) developed over the northeastern Atlantic, with its center to the north of Scotland. Two smaller and weaker negative anomalies also formed, one off the eastern United States and another over northern Africa. A positive anomaly was centred over Davis Strait and northern Greenland (3-5 mb) with a ridge of higher-than-normal pressures extending from southern Labrador through to Africa. In eastern Canada, the geostrophic winds associated with these anomaly pressure fields would be predominantly from the south and east.

As is typical in most years, the pressure anomaly field during the summer of 1999 was generally weaker than in the other seasons. Slightly lower pressures than normal covered most the North Atlantic. There were several local maxima, all of which were slightly above 2 mb. These were found over the Labrador coast, over Baffin Island, west of Ireland and over northern Africa. The geostrophic winds accompanying this pressure anomaly field were also relatively weak.

In the autumn, there was a return to the wintertime pattern with an intensification of the Icelandic Low and Azores High, although their amplitudes were much reduced from winter. Also the spatial size of the High was smaller than in the winter. The southwesterly winds associated with the High over eastern Canada would have contributed to the warm fall temperatures over the region.

NAO Index

The North Atlantic Oscillation (NAO) Index is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly winds over the northern North Atlantic (Rogers, 1984). A high NAO index corresponds to an intensification of the Icelandic Low and Azores High. Strong northwest winds, cold air and sea temperatures and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index (Colbourne et al. 1994; Drinkwater 1996). The annual NAO index is derived from the measured mean sea level pressures at Ponta Delgada (up to 1997) or Santa Maria (since 1997) in the Azores minus those at Akureyri in Iceland. The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1961-90 mean.

In 1999, the NAO anomaly was well above normal (+14.3 mb) and had increased significantly from the 1998 value which was +1.1 mb (Fig. 6). Indeed, the 1999 index returned to a level similar to that observed during the first half of the 1990s and was above the lower-than-average indices registered in 1996 and 1997. These changes in the NAO index fit the pattern of quasi-decadal variability that has persisted since the 1960s. As described above, high NAO is usually accompanied by cold conditions over the Labrador Sea in winter. This did not occur over the western Labrador Sea and the Newfoundland region during 1999 as air temperatures in southern Labrador and Newfoundland set new high records. Two possible causes of the break down in the NAO air temperature relationship in the Labrador-Newfoundland area. First, the anomalous winter pressure field showed most of the activity over the eastern North Atlantic with weaker gradients over the Northwest Atlantic (Fig. 5). Second, the Azores High in winter extended into southeastern Canada (Fig. 5)

SEA ICE OBSERVATIONS

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The long-term median, maximum and minimum positions of the ice edge (concentrations above 10%) based on the composite for the years 1962 to 1987 are taken from Coté (1989). We also include an analysis of the time of onset, duration and last presence of sea ice in the Gulf of St. Lawrence and on the Scotian Shelf based upon the sea-ice database maintained at the Bedford Institute of Oceanography (Drinkwater et al., 1999). The weekly concentration and types of ice within 0.5º latitude by 1º longitude areas were recorded through the ice season. The dates of the first and last appearance of ice within these areas, as well as the duration of ice, were determined. The database begins in the early 1960s and continues to the present. Long-term means (30-years, 1964-1993) of each variable were determined (using only data during the years ice was present) and subtracted from the 1999 values to obtain anomalies. Last year we also included a similar analysis for the southern Labrador and northern Newfoundland shelves based upon the database maintained by Prinsenberg and Peterson (1990). However, as of the time of writing these data were unavailable for 1999.

Newfoundland and Labrador

At the end of 1999, sea ice lay off the southern Labrador coast in the vicinity of Hamilton Inlet resulting in an areal coverage that matched closely the long-term median for that time of the year (Fig. 7a). This was aided by below normal air temperatures and strong northwest winds during the latter half of December. By mid-January, the ice had spread past the southern tip of Labrador and onto the northern Newfoundland coast, which was a little further south than its long-term median position. Elsewhere, however, the ice edge was near its median position. During the latter half of January light west to northwest winds prevailed and air temperatures were generally 1°-3°C above normal. By the first of February, the ice edge extended south to Notre Dame Bay and the ice extent and thickness were near normal. In spite of the warmer-than-normal air temperatures (3°-5°C) and light winds during February, by 1 March, the southern most ice edge still lay close to the long-term median position. However, the ice did not extend as far offshore as normal resulting in less ice extent than normal. This was in part due to the persistent northeast winds during the second half of February, which pushed ice shoreward. Winds from the southwest and above normal air temperatures during most of March resulted in an early retreat of the ice and by 1 April, the ice edge was inshore of its long-term median position on the northern Newfoundland shelf, although near it off southern Labrador (Fig. 7b). Warm air temperatures continued throughout April with the result that the ice continued to retreat faster-than-normal. By 1 May, the ice was restricted to the nearshore areas off northern Newfoundland and the inner

Labrador Shelf. The ice edge lay well inshore of the long-term median location. On 1 June, the ice had retreated to the Labrador Shelf region north of Hamilton Inlet. The ice edge was near its normal position but the ice thickness was less than normal. By 1 July all traces of ice had disappeared from southern Labrador.

The time series of the areal extent of ice on the Newfoundland and southern Labrador shelves (between 45-55°N; I. Peterson, personal communication, Bedford Institute) show that the peak extent during 1999 was close to, but slightly below that observed in 1998 and the lowest since 1978 (Fig. 8). Relative to 1998, the average ice area during the period of general advancement (January to March) rose slightly but declined during the period of retreat (April to June). During both advance and retreat periods, the average ice area was below the long-term mean and was much less than the early 1990s. The monthly means of ice area show that in 1999 coverage was above that in 1998 in December and January but below for February to April (Fig. 9). In May to July the ice area was similar to the previous year. Except for January, the monthly mean ice area was below the long-term mean (1963-1990). In summary, 1999 was generally a lighter-than-average ice year on the Labrador and Newfoundland shelves.

No estimates of ice volume were made for 1999 but based upon studies in the Gulf of St. Lawrence its temporal variability is similar to that of the ice area (Drinkwater et al., 1999).

Icebergs

The International Ice Patrol Division of the United States Coast Guard monitors the number of icebergs that pass south of 48°N latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). During the 1998/99 iceberg season (October 1998 to September 1999), a total of only 22 icebergs were spotted south of 48°N. The monthly totals for March to July were 1, 2, 11, 5, and 3, respectively (Fig. 10). No icebergs were spotted between October 1998 and February 1999, inclusive, or in August or September 1999. In 1999, all of the icebergs were observed during the primary iceberg season of March to July, which is higher than the 1983-99 mean of 91.4%. Half of the icebergs during the 1998/99 season drifted south of 48°N in May but the low number of icebergs overall makes this statistic less meaningful than in recent years. The total number of icebergs in 1999 was down dramatically from the 1384 icebergs recorded in 1998 and was the 11th fewest in the 120-year record (Fig. 10). The low number of icebergs in 1999 is consistent with reduced sea ice coverage and warm air temperatures off southern Labrador and northern Newfoundland. This is believed to be due to increased melting caused by the warmer air temperatures and greater deterioration of the icebergs from breaking waves when there is less sea ice (Marko et al., 1994).

Gulf of St. Lawrence

At the end of December 1998, ice was present only in nearshore regions in the Gulf of St. Lawrence including within the St. Lawrence Estuary, along the northshore of Quebec, and along the northern and eastern shores of New Brunswick (Fig. 11). Air temperatures during the first half of January were generally below normal by 1°-2°C. This resulted in the ice covering the eastern half of the Gulf and along the northshore of Quebec by mid-month. At this time, the ice was near to, but slightly greater than, its normal extent. During the latter half of January, air temperatures rose above normal. The areal extent continued to expand so that by 1 February the ice coverage was again near to but slightly greater than the long-term median. The very high air temperature anomalies during February lead to little seaward advancement of the ice edge by 1 March over that recorded at the beginning of February. Again the ice thickness was less than normal at this time. During March the continuing high air temperature anomalies caused a rapid retreat so that there was much less ice than normal by 1 April when ice was confined to the southeastern Gulf, off eastern Cape Breton and in the vicinity of the Strait of Belle Isle. The small amount of ice gradually disappeared through April so that by May 1, the only ice left was in the Strait of Belle Isle region. This ice was probably advected into the Gulf from the Labrador Shelf.

During 1999 within the Gulf (landward of Cabot Strait), the first ice formation ranged from late December in the St. Lawrence Estuary and in the eastern region of the Magdalen Shallows to early February (after day 30) off southwestern Newfoundland (Fig. 12). Although within 10 days of the typical date, it was generally an earlier-than-normal appearance (Fig. 13). The date of last appearance shows the standard pattern of ice lasting longest over the southern Magdalen Shallows and along the north shore of Quebec through to the Strait of Belle Isle (Fig. 12). In 1999, the anomaly in the date of last presence varied throughout the Gulf, with ice leaving earlier-than-normal in much of region but still significant portions where it left later (Fig. 13). For the former, the magnitude of the anomalies tended to be longer, upwards of 40 days early off southwest Newfoundland. The duration of ice ranged from less than 20 days off southwestern Newfoundland to over 130 days in the Strait of Belle Isle (Fig. 14). Relative to the long-term mean, using only years when ice was present, ice duration was less than normal throughout much of the Gulf, exceptions being in the vicinity of Anticosti Island and the western region of the Magdalen Shallows around Prince Edward Island and extending through to the Gaspe Peninsula. Near Cabot Strait and off southwest Newfoundland, the duration of ice was more than 40 days less than the long-term mean.

Scotian Shelf

Sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwest winds and the mean ocean currents. In 1999, ice first appeared seaward of Cabot Strait during mid-January (Fig. 12), which is typical. It maintained a relatively constant presence through into early March on the Newfoundland side of the Strait and mid-April off northern Cape Breton. This ice was primarily restricted to the Sydney Bight area with little ice reaching the Scotian Shelf proper. Most of this ice had disappeared by the end of March or in early April (Fig. 12). This departure was about 10 days earlier-than-normal. The duration of ice south of Cabot Strait ranged from 70 days off northern Cape Breton Island to 10 days or less off southeastern Cape Breton Island. This was less than the long-term mean by 10 to over 40 days (Fig. 14). Note that durations of less than 10 days are not plotted in Fig. 14.

The monthly estimates of the ice area seaward of Cabot Strait since the 1960s show that only small amounts were transported onto the Scotian Shelf during 1999 compared to the long-term mean (Fig. 15, 16). It was, however, similar in magnitude to the ice area observed in 1998. There were fewer-than-usual number of days when ice was present seaward of Cabot Strait and the integrated ice area (summation of the area times the number of days) was the fourth lowest on record (Fig. 15). In summary, 1999 was the second consecutive year of very light ice conditions seaward of Cabot Strait. Note that based upon data collected since the 1960s, the furthest south that the ice penetrates is along the Atlantic coast of Nova Scotia to just past Halifax. Historical records prior to 1960, albeit incomplete, suggest that during heavy ice years, it occasionally penetrated much further south, for example in the 1880s sea ice was observed in the Gulf of Maine (A. Ruffman, Geomarine Associates Ltd., Halifax, personal communication).

SUMMARY

During 1999, the NAO index returned to the high values seen during the early 1990s after 3 years of below normal and near normal values. The index rose by over 13 mb compared to 1998 as a result of the intensification of the Icelandic Low and Azores High. Air temperatures over most of the northwest Atlantic region were above normal continuing the warming trend of the past 2 years. Indeed, from southern Labrador to the Gulf of Maine, 1999 ranked as the warmest year on record, some of which go back over 120 years. In the Gulf of St. Lawrence and the Scotian Shelf the annual air temperatures in 1999 increased over 1998 values by approximately 1°C. The exception to the warm conditions was in West Greenland where available air temperatures indicate colder-than-normal conditions. Between southern Labrador and the Gulf of Maine, almost all months in 1999 experienced warmer-than-normal temperatures, the exceptions being October and November. The relatively warm winter temperatures resulted in less ice than normal off Newfoundland and Labrador, and in the Gulf of St. Lawrence. Ice generally arrived on schedule but left early, causing fewer days of ice in these areas. It also was thinner than usual. Little ice reached the Scotian Shelf proper and seaward of Cabot Strait the amount of ice was the 5th lowest in the 38-year record. With the reduced amount of sea ice later in the season off Newfoundland and warmer air temperatures, the number of icebergs reaching the northern Grand Banks in 1999 fell sharply to only 22 bergs from 1384 in 1998. The number of icebergs was well below the long-term average and the lowest number since 1980. Past studies have shown cold air temperatures and extensive ice off Newfoundland and Labrador are usually associated with high NAO years (Colbourne et al., 1994; Drinkwater et al., 1996). This was not the case in 1999. In this year, the cold conditions during the high NAO phase were confined to the Greenland side of the Labrador Sea. The warm conditions, especially in the winter, over much of eastern Canada was due to the extended influence of the Azores High and its associated southerly winds.

ACKNOWLEDGEMENTS

We wish to thank all those who provided data, especially to I. Peterson of the Bedford Institute for the monthly areal ice extent data for the Newfoundland region, and to E. Colbourne for comments on an earlier draft of this paper.

REFERENCES

Colbourne, E., S. Narayanan and S. Prinsenberg. 1994. Climatic changes and environmental conditions in the Northwest Atlantic, 1970-1993. ICES mar. Sci. Symp. 198: 311-322.

Coté, P.W. 1989. Ice limits eastern Canadian seaboard. Environment Canada, Ottawa. 39 p. (Unpublished Manuscript)

Deutschen Wetterdienstes. 1999. *Die Grosswetterlagen Europas*. Vol. 52. Offenbach, Germany.

Drinkwater, K.F. 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early-1990s. J. Northw. Atl. Fish. Sci. 18: 77-97.

Drinkwater, K.F., R.G. Pettipas, G.L. Bugden and P. Langille. 1999. Climatic data for the Northwest Atlantic: A sea ice database for the Gulf of St. Lawrence and the Scotian Shelf. Can. Tech. Rept. Hydrogr. Ocean Sci. 199: 134 p.

Marko, J.R., D.B. Fissel, P. Wadhams, P.M. Kelly and R.D. Brown. 1994. Iceberg severity off eastern North America: its relationship to sea ice variability and climate change. J. Climate 7: 1335-1351.

NOAA. 1999. *Monthly climatic data for the world*. Vol. 52. National Climate Data Center, Asheville, North Carolina.

Peterson, I. K. and S. J. Prinsenberg. 1990. Sea ice fluctuations in the western Labrador Sea (1963-1988). Can. Tech. Rep. Hydrogr. Ocean Sci. 123: 130 p.

Rogers, J.C. 1984. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. Mon. Wea. Rev. 112: 1999-2015.

Thompson, K.R. and M.G. Hazen. 1983. Interseasonal changes in wind stress and Ekman upwelling: North Atlantic, 1950-80. Can. Tech. Rep. Fish. Aquat. Sci. 1214, 175 p.

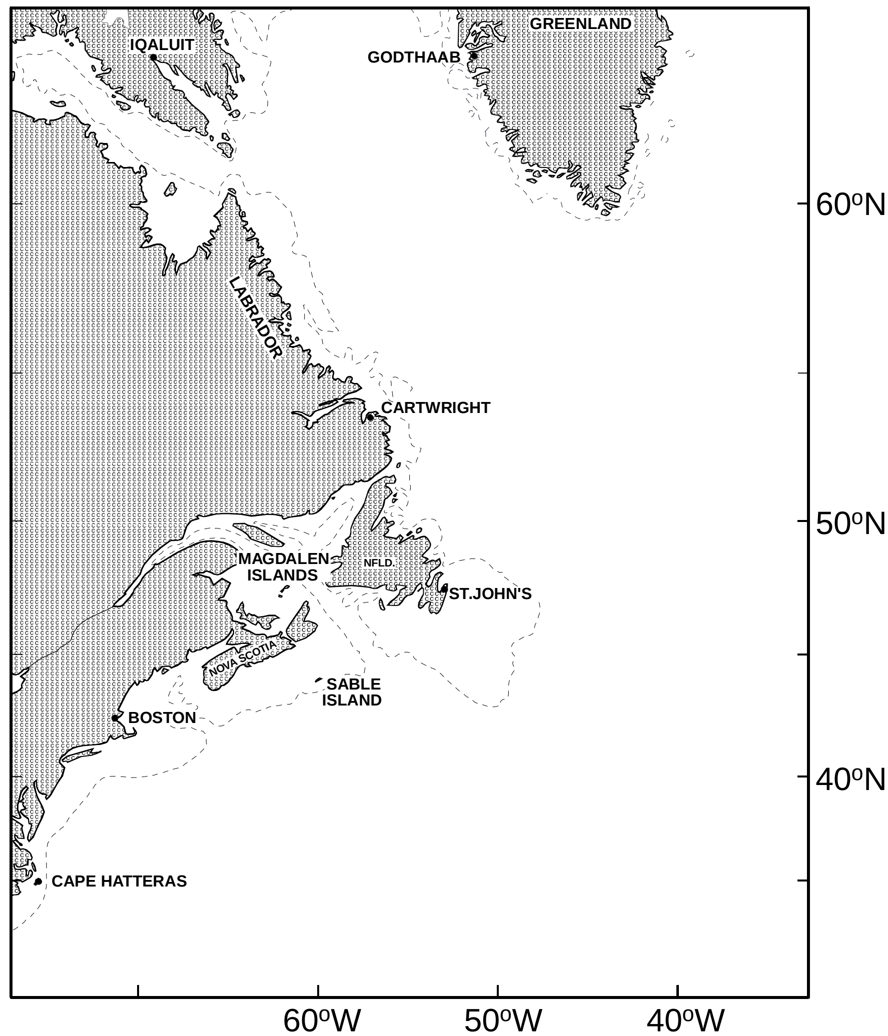


Fig. 1. Northwest Atlantic showing coastal air temperature stations. The dashed line denotes the 200 m isobath.

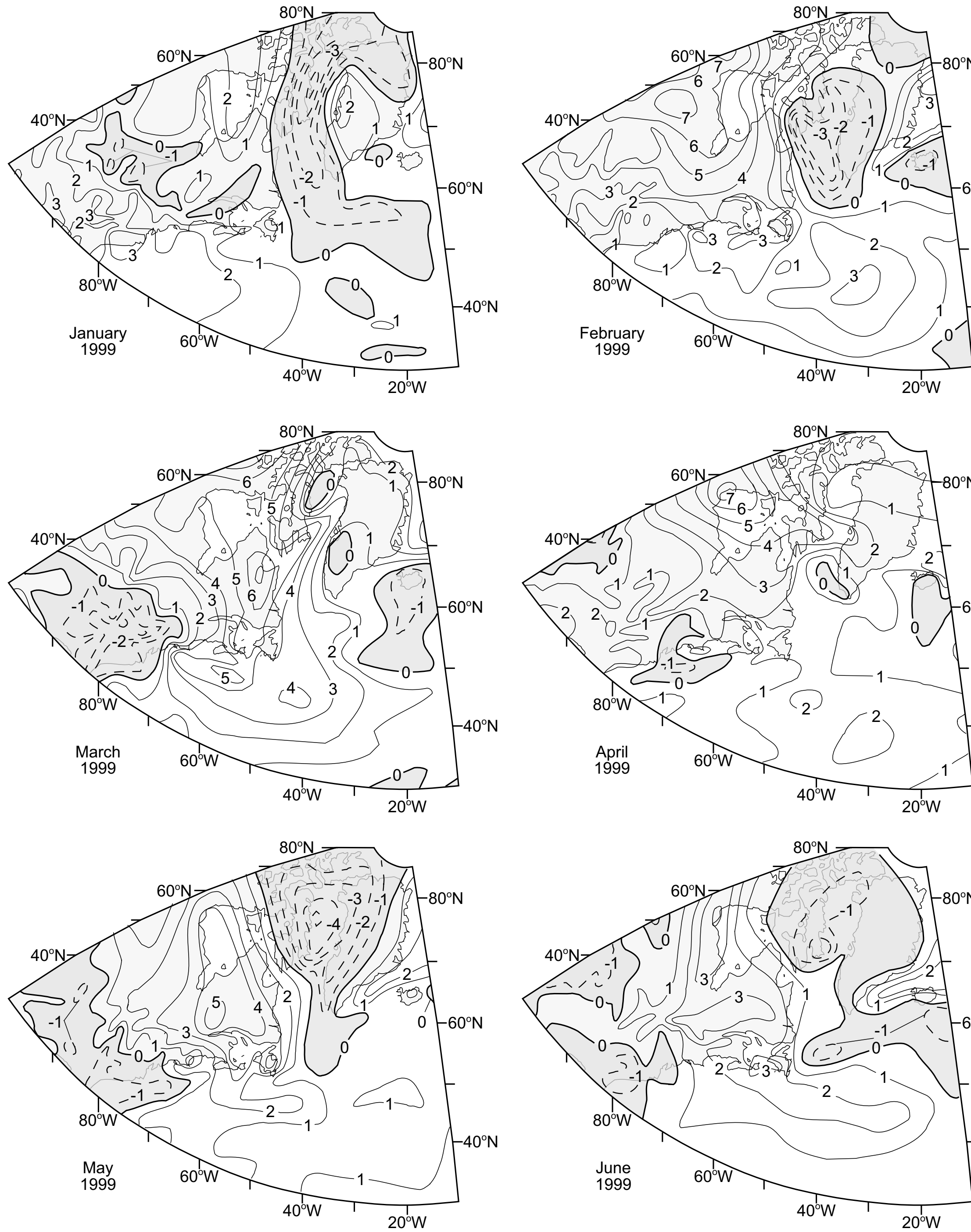


Fig. 2. Monthly air temperature anomalies (ºC) over the Northwest Atlantic and eastern Canada in 1999 relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

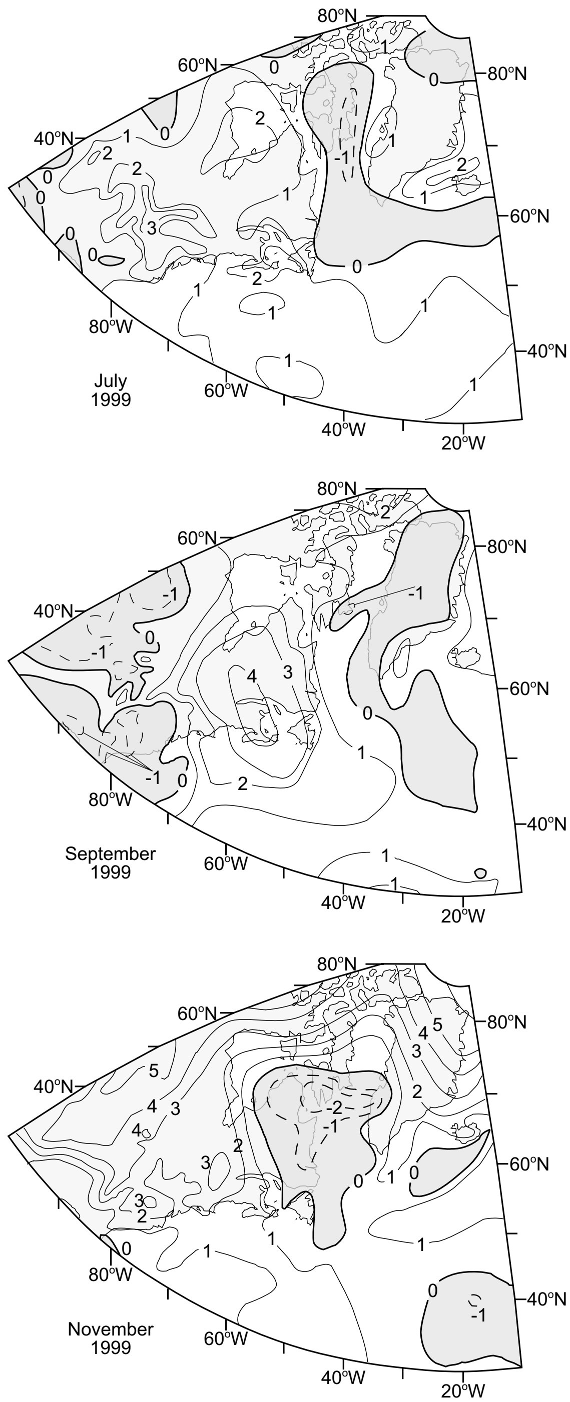


Fig. 2 (continued). Monthly air temperature anomalies (°C) over the Northwest Atlantic and eastern Canada in 1999 relative to the 1961-90 means. The darker shaded areas are colder-than-normal. (From *Grosswetterlagen Europas*)

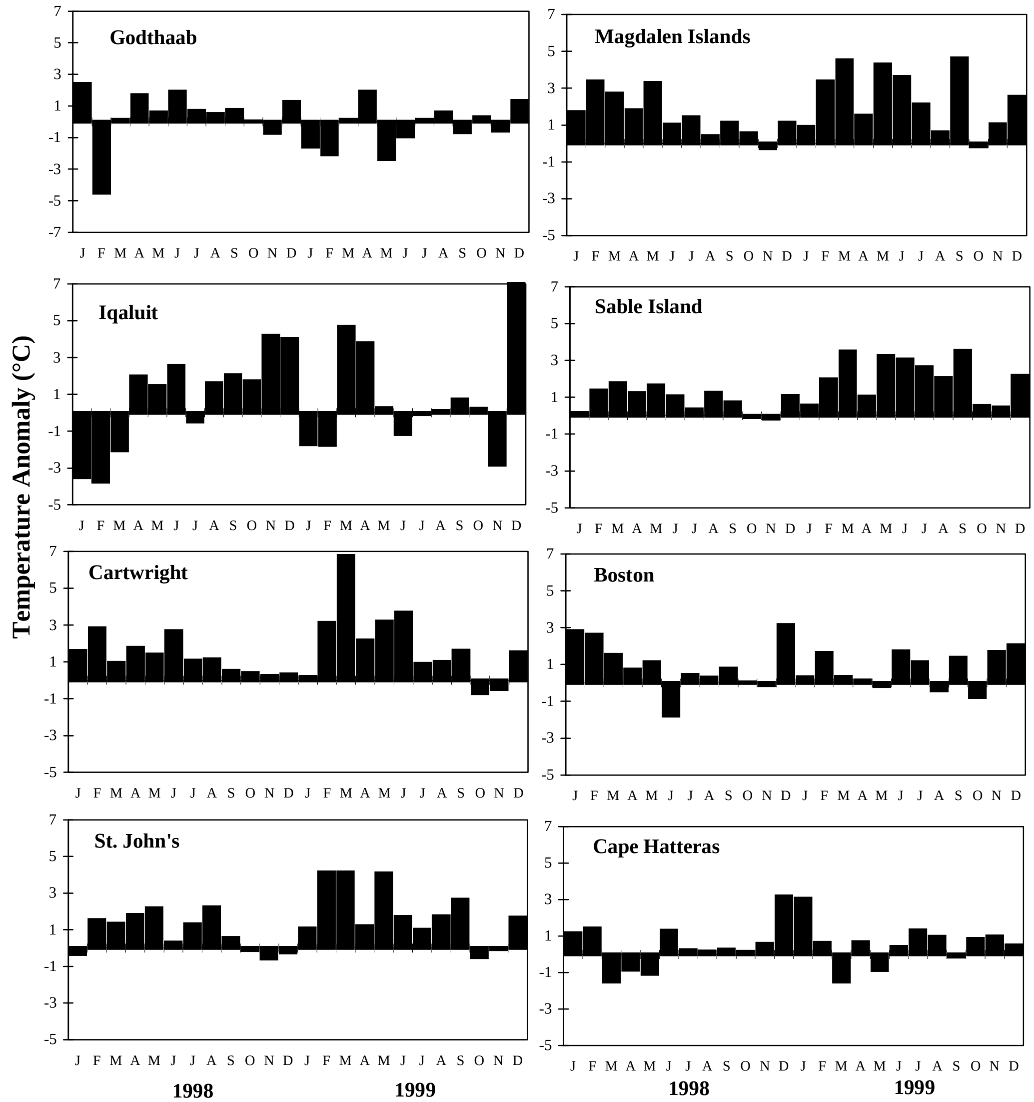


Fig. 3. Monthly air temperature anomalies in 1998 and 1999 at selected coastal sites (see Fig. 1 for locations).

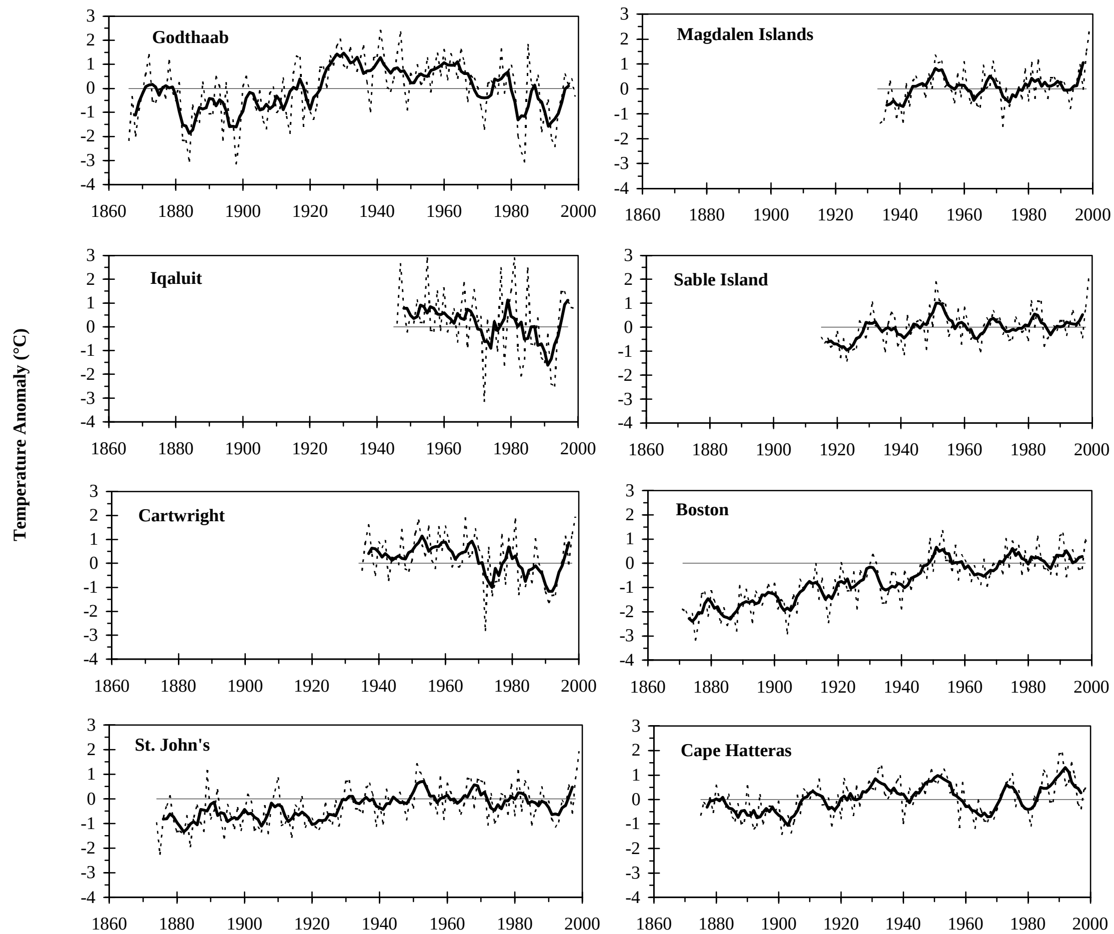


Fig. 4. Annual air temperature anomalies (dashed line) and 5-yr running means (solid line) at selected sites.

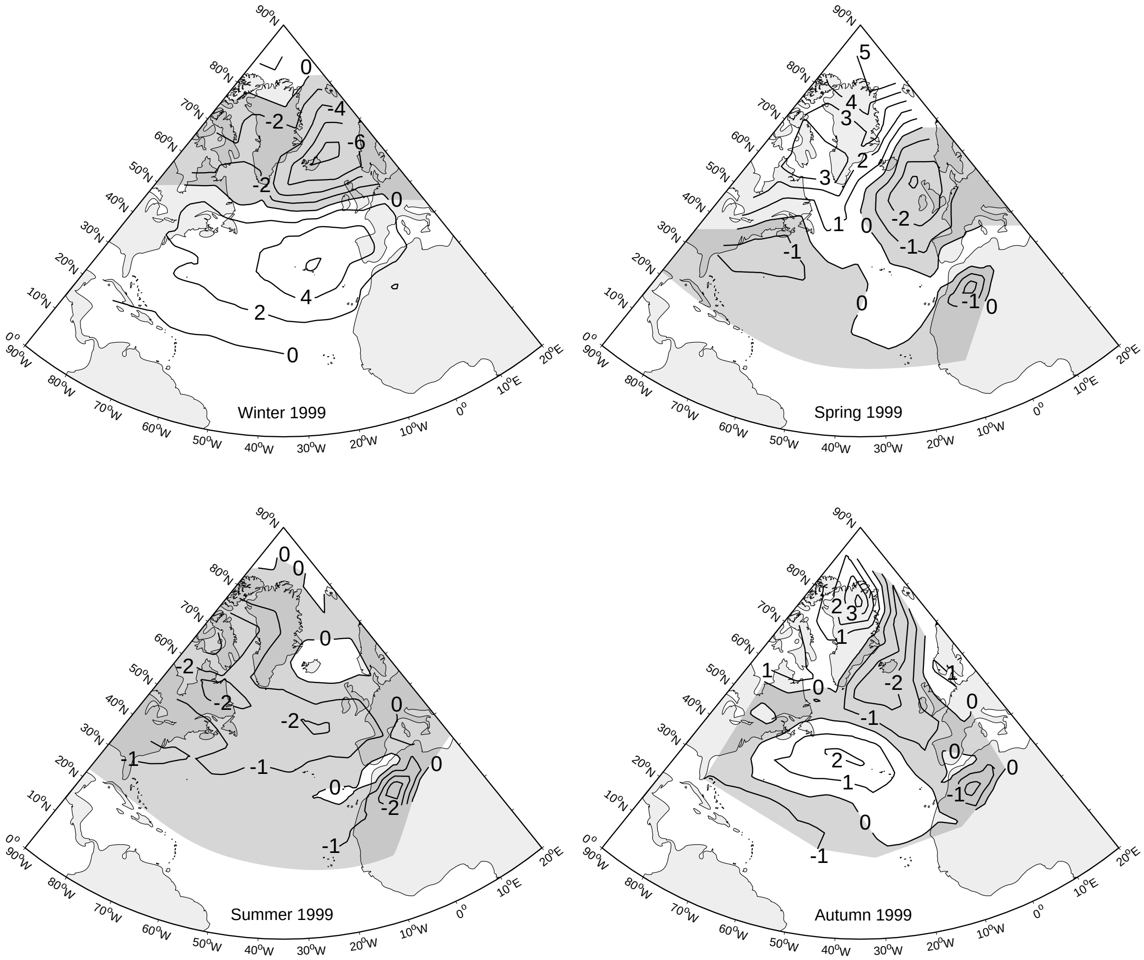


Fig. 5. Seasonal sea-surface air pressure anomalies (mb) over the North Atlantic in 1999 relative to the 1961-90 means.

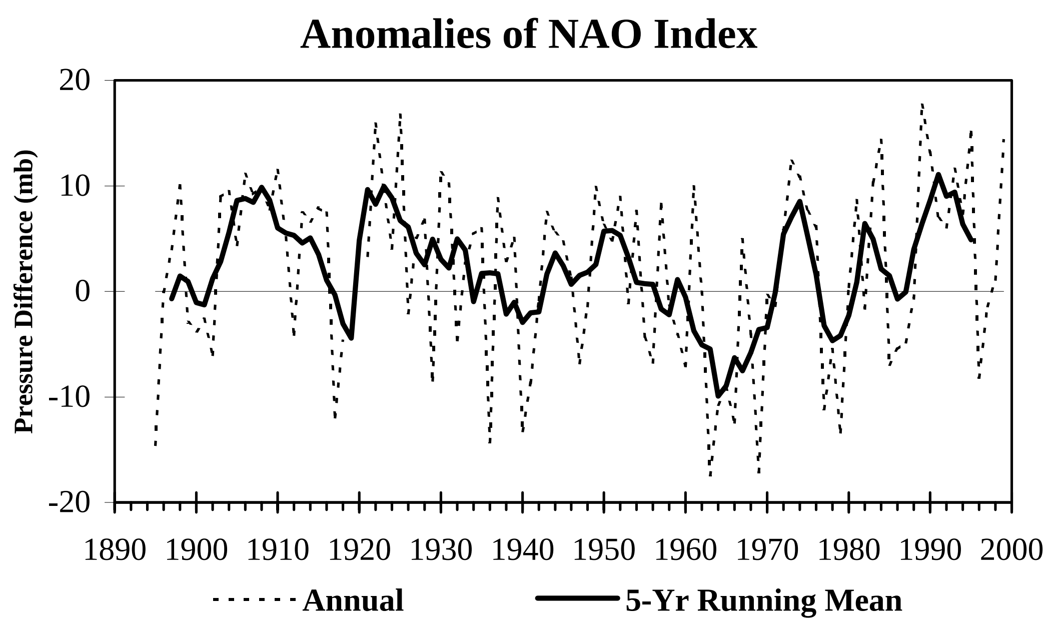


Fig. 6. Anomalies of the North Atlantic Oscillation Index, defined as the winter (December, January, February) sea level pressure at Ponta Delgada in the Azores minus Akureyri in Iceland, relative to the 1961-90 mean.

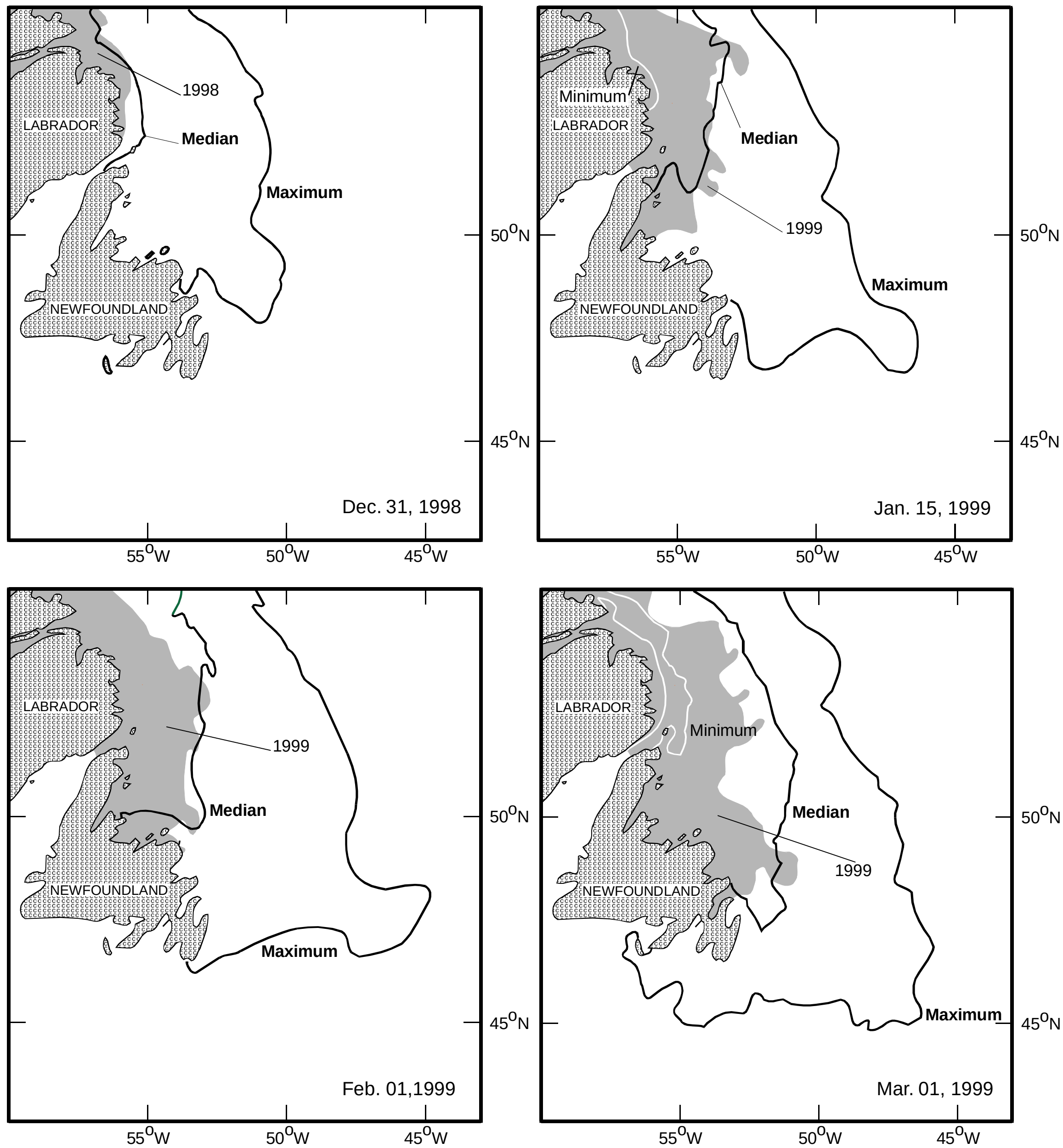


Fig. 7a. The location of the ice (shaded area) between December 1998 and March 1999 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

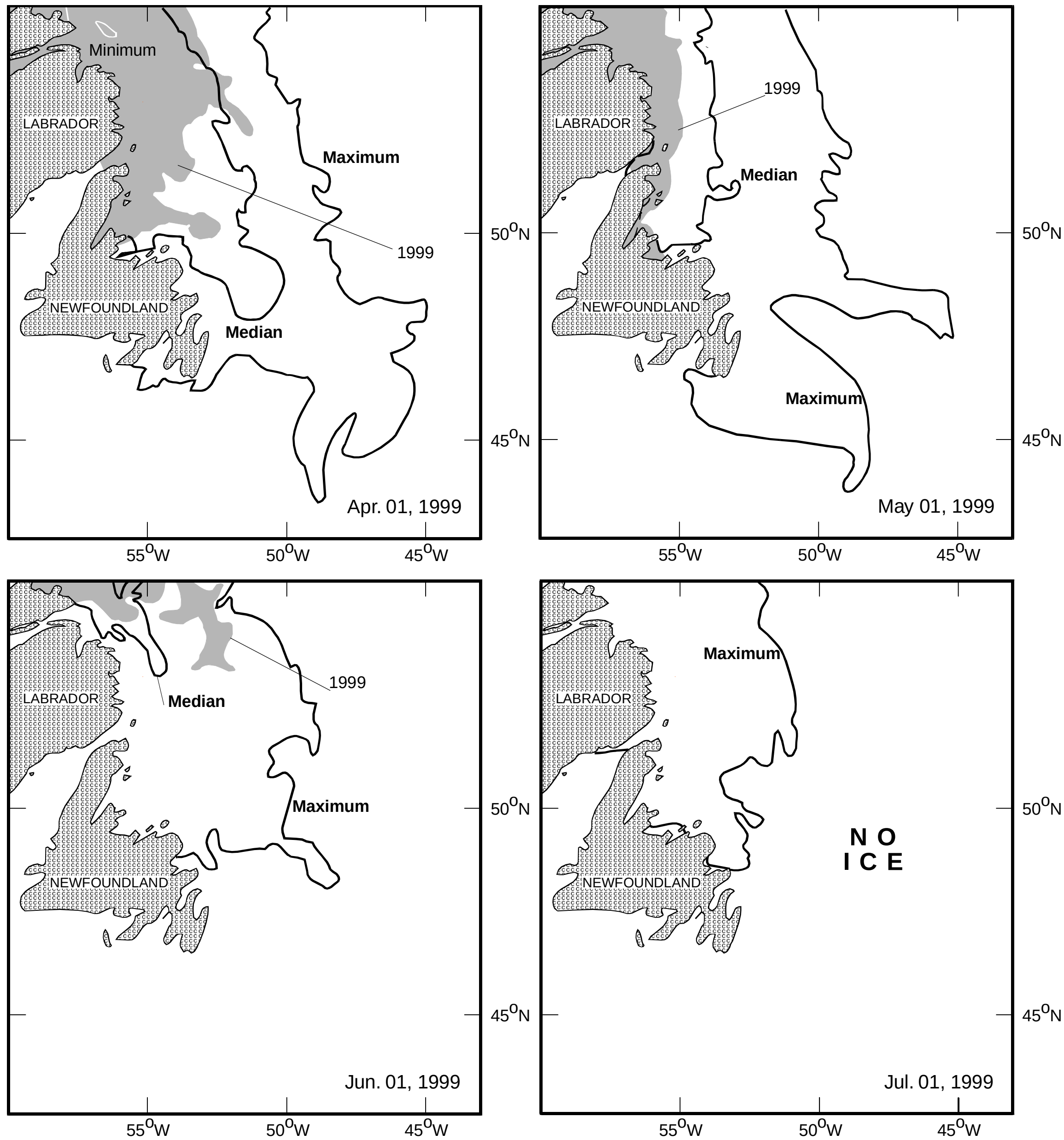


Fig. 7b. The location of the ice (shaded area) between April and July 1999 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge off Newfoundland and Labrador.

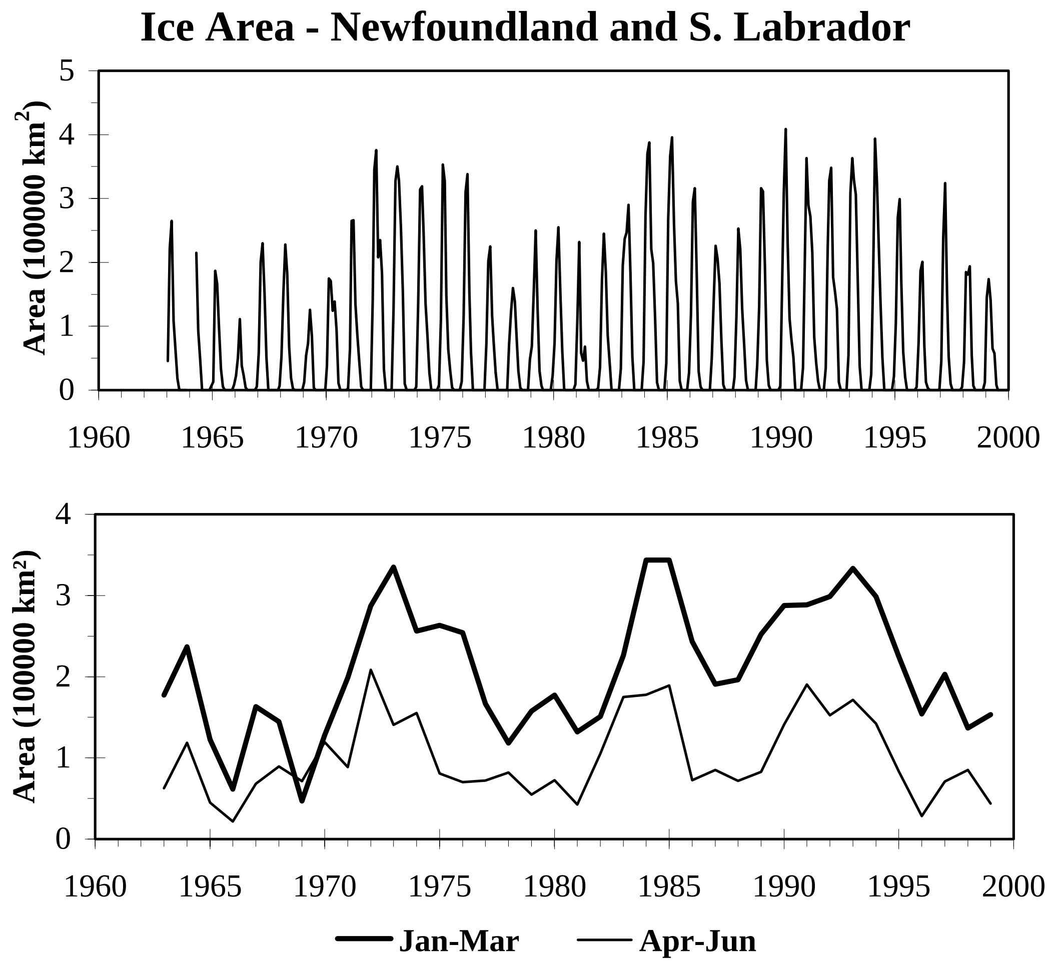


Fig. 8. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

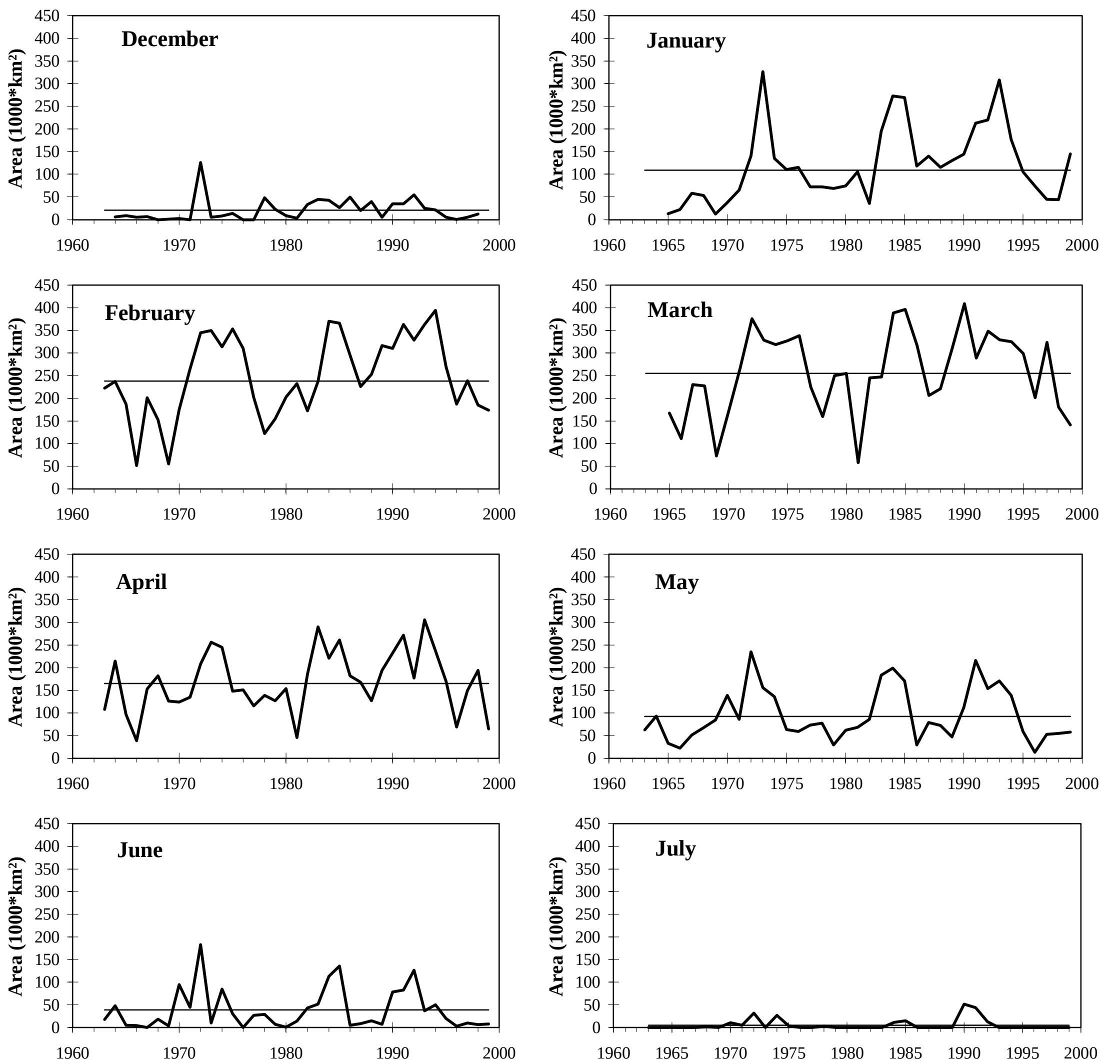
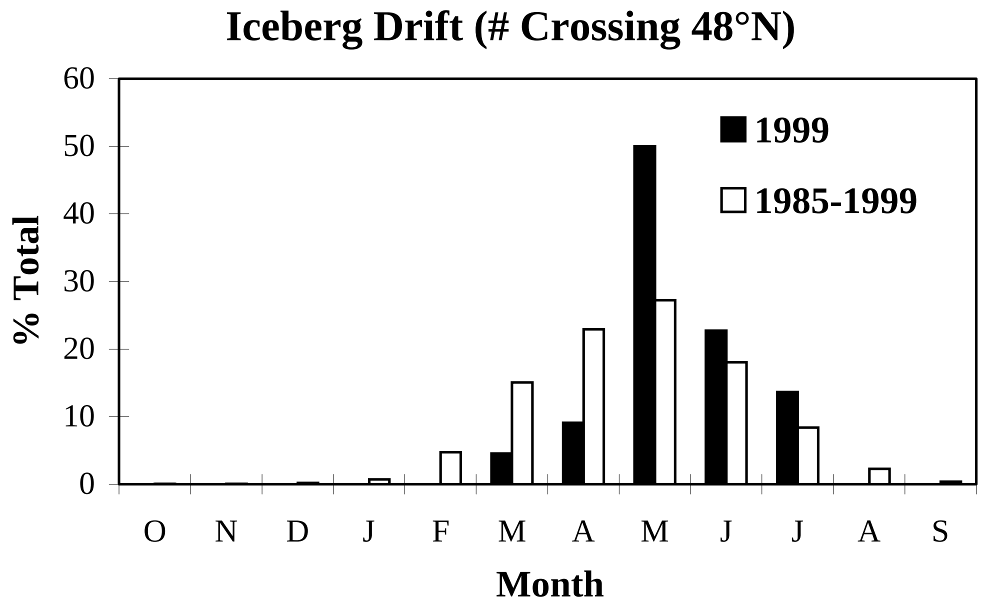


Fig. 9. The time series of ice area off Newfoundland and Labrador, by month. The horizontal lines represent the long-term (1963-90) means.



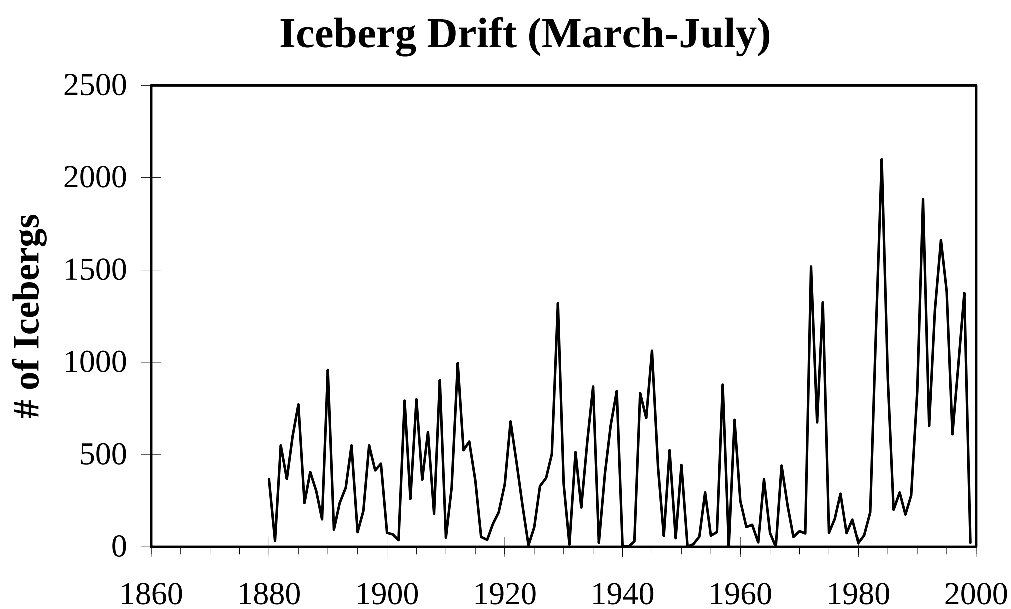


Fig. 10. The number of icebergs crossing south of 48°N during the iceberg season 1998/99 expressed as a percent of the total by month compared to the mean during 1983-99, the years SLAR has been used (top panel) and the time series of total number of icebergs observed during March to July (bottom panel).

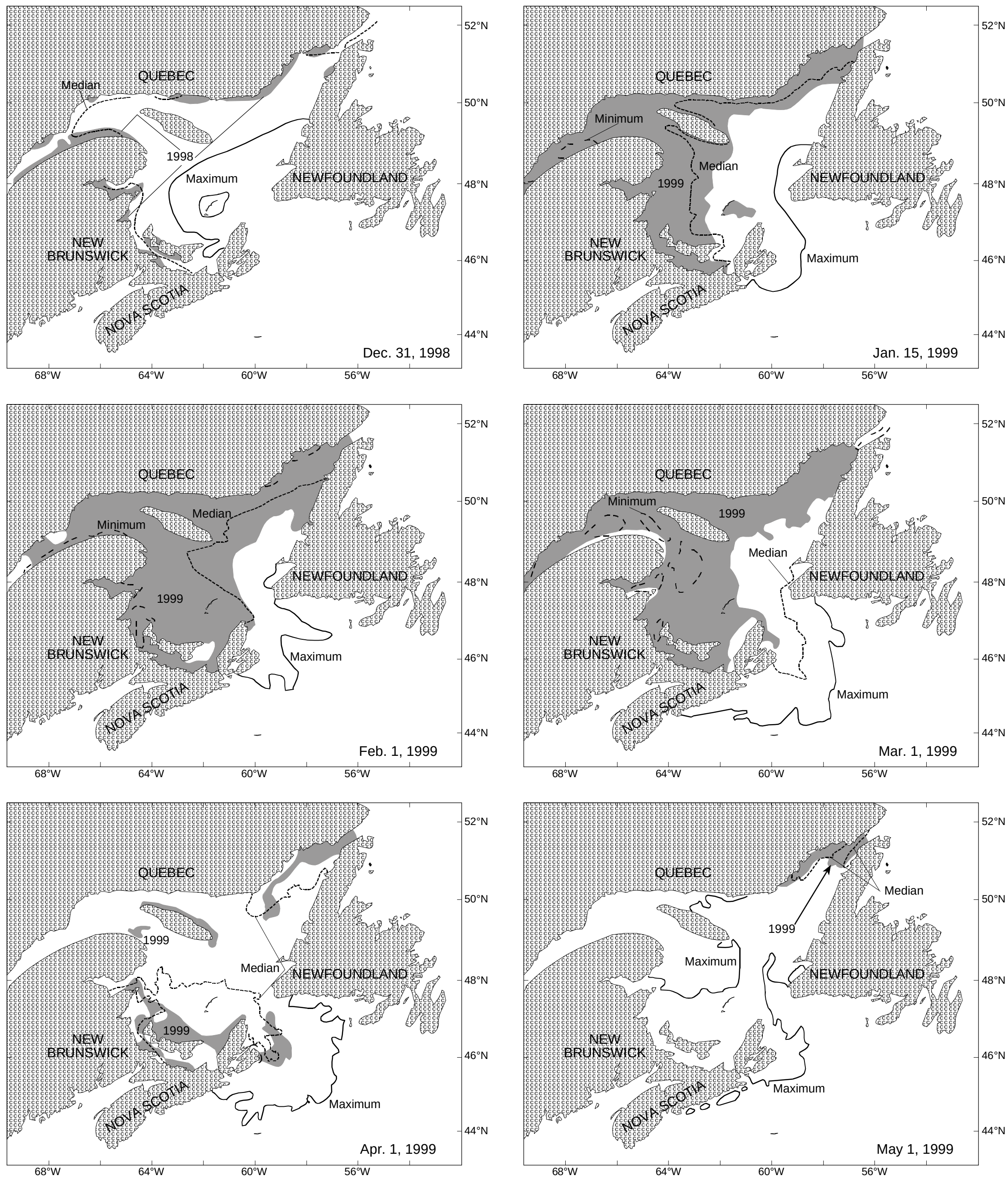


Fig. 11. The location of the ice (shaded area) between December 1998 and May 1999 together with the historical (1962-1987) minimum, median and maximum positions of the ice edge in the Gulf of St. Lawrence.

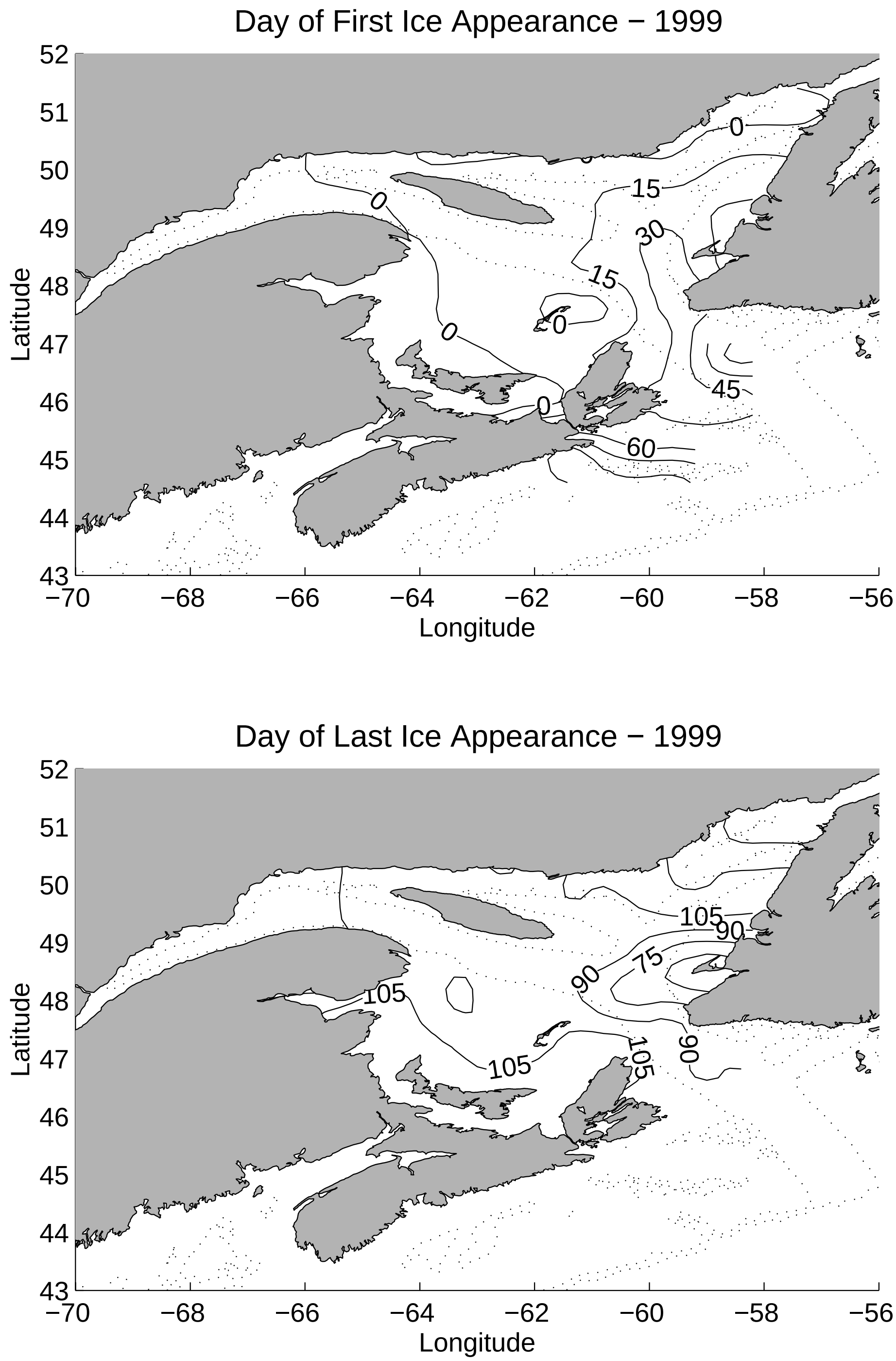


Fig. 12. The time when ice first appeared (top panel) and last appeared (bottom panel) during 1999 in days from the beginning of the year.

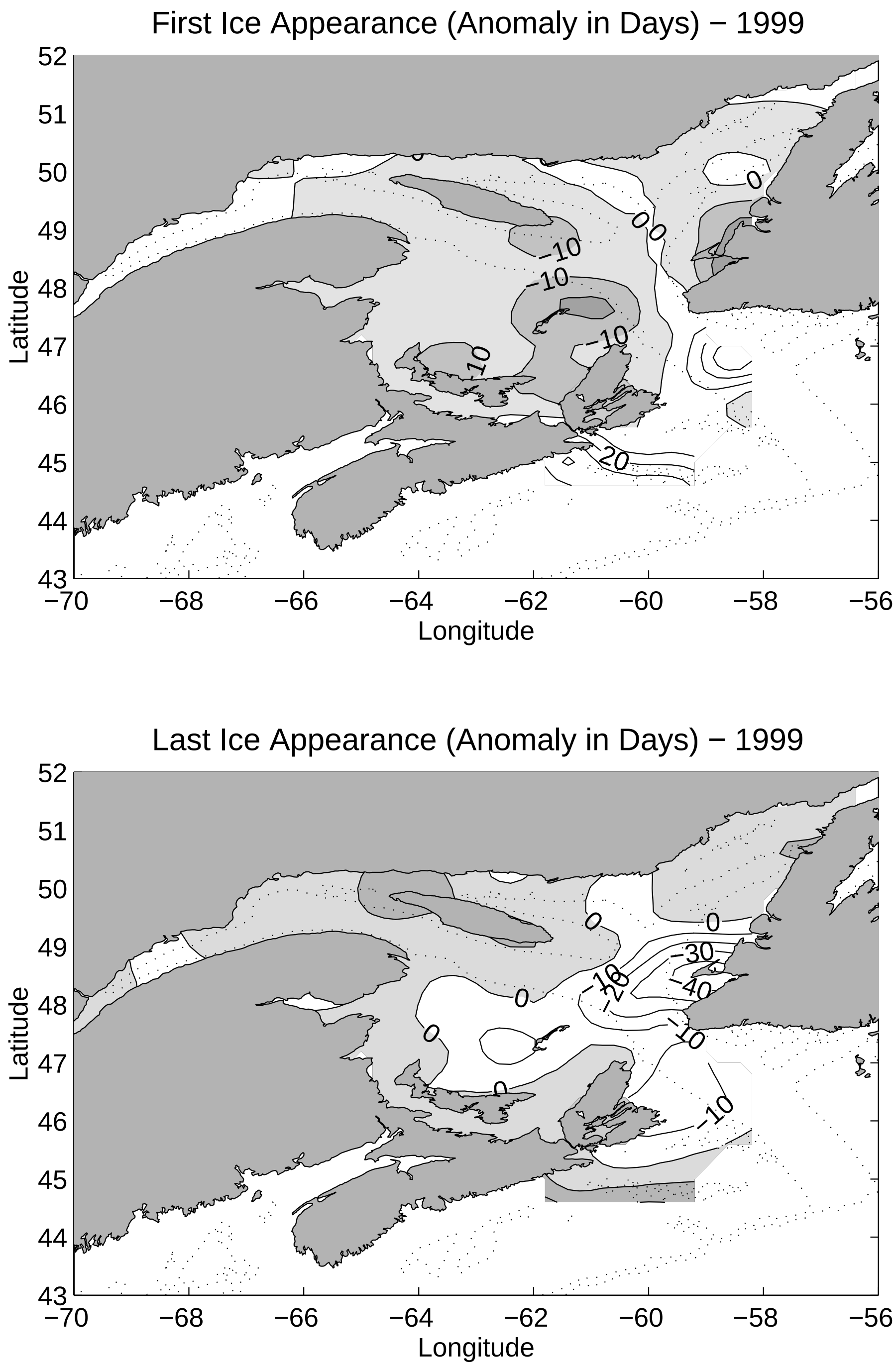


Fig. 13. The anomaly of the time when ice first appeared (top panel) and was last reported (bottom panel) during 1999 in days from the beginning of the year. Negative anomalies indicate earlier-than-normal and positive are later-than-normal. The shaded anomalies indicate conditions generally associated with cold years, i.e. earlier ice appearance and later-than-normal disappearance.

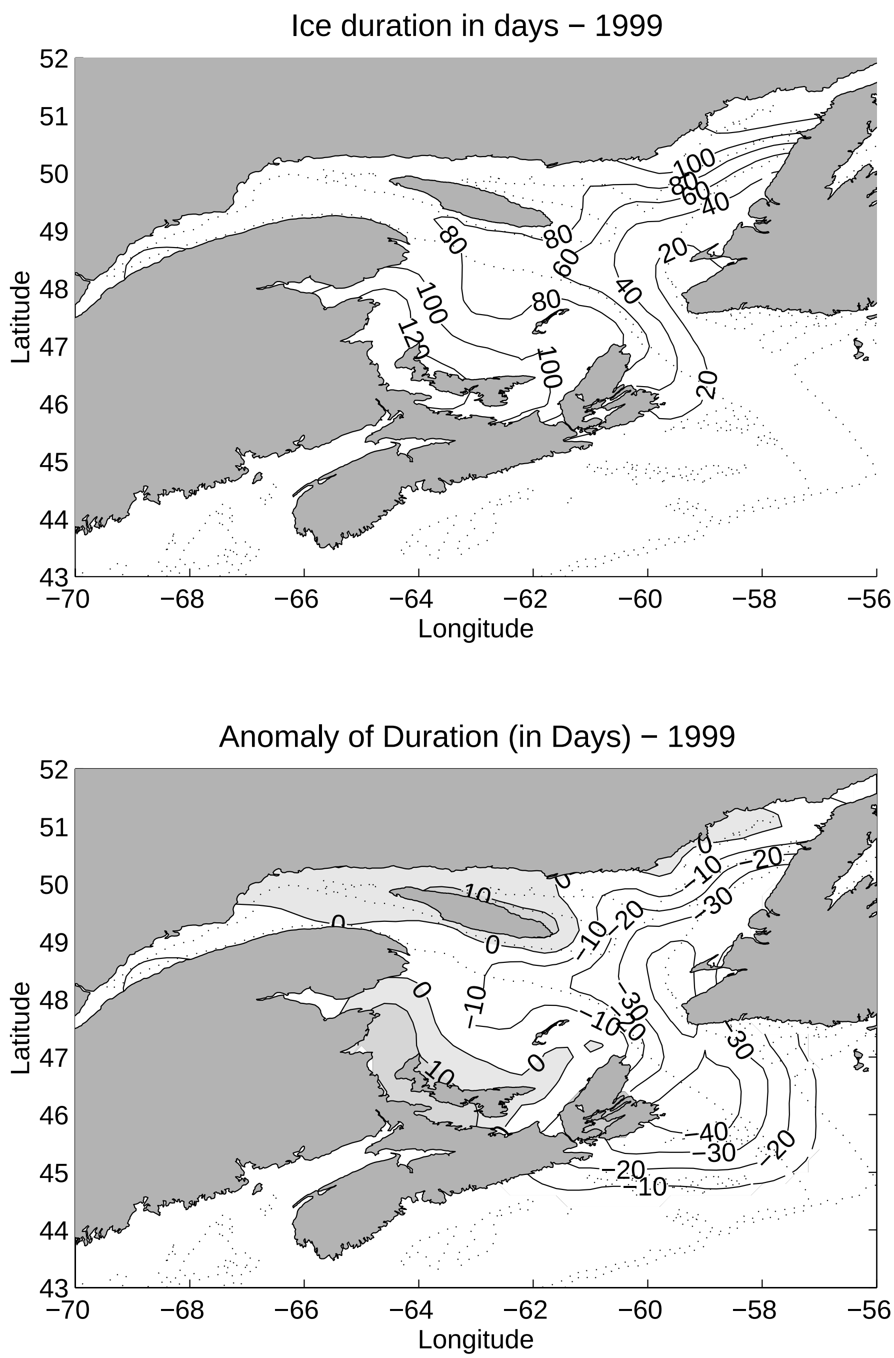


Fig. 14. The duration of ice in days (top panel) and their anomaly from the long term mean in days (bottom panel). The shaded positive anomalies indicate a duration longer than the mean, which is generally associated with a cold year.

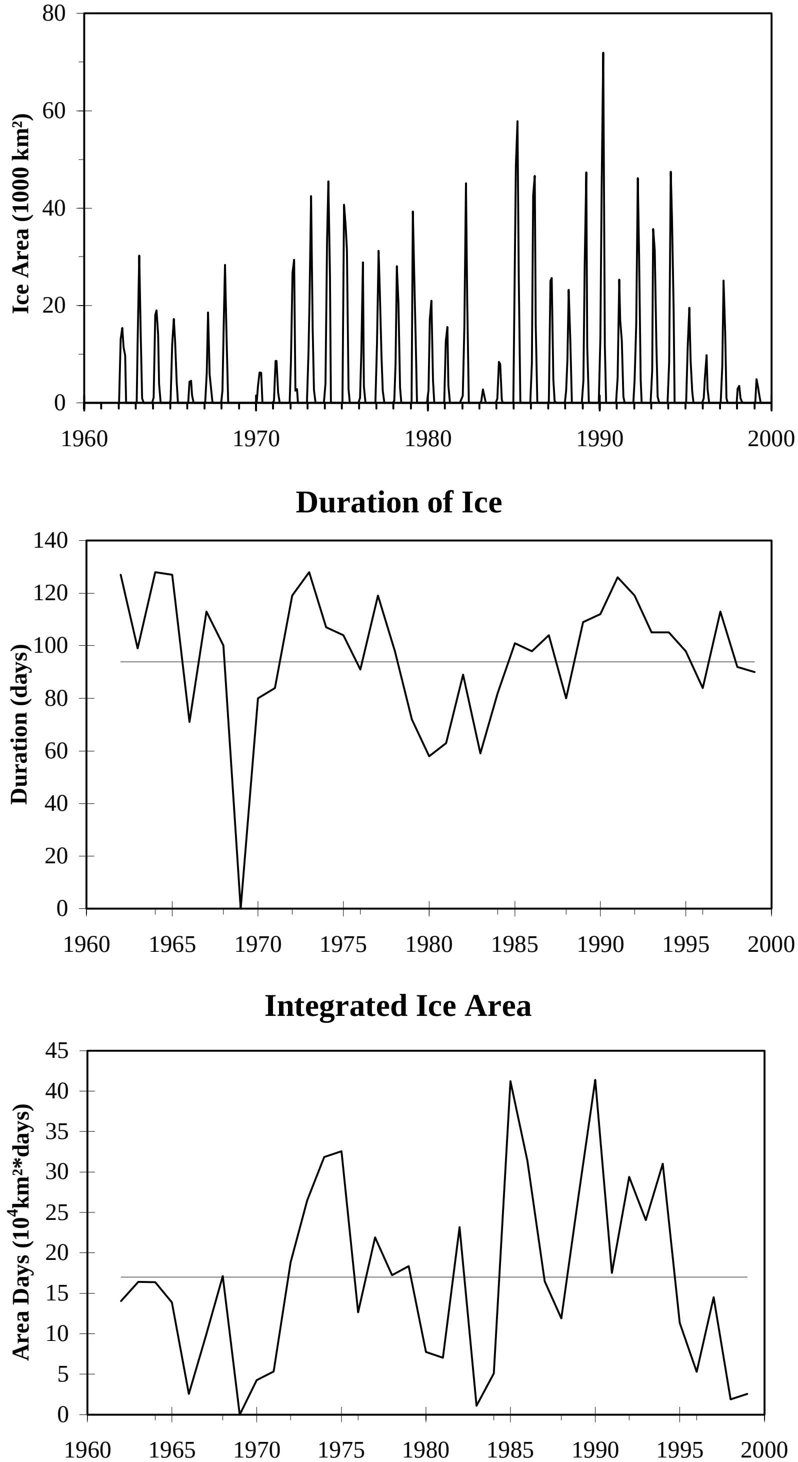


Fig. 15. For the region seaward of Cabot Strait, the time series of the monthly mean ice area (top), the duration of ice (middle) and the annual integrated ice area (summation of the area times the number of days). The horizontal lines represent the long-term (1962-1990) means.

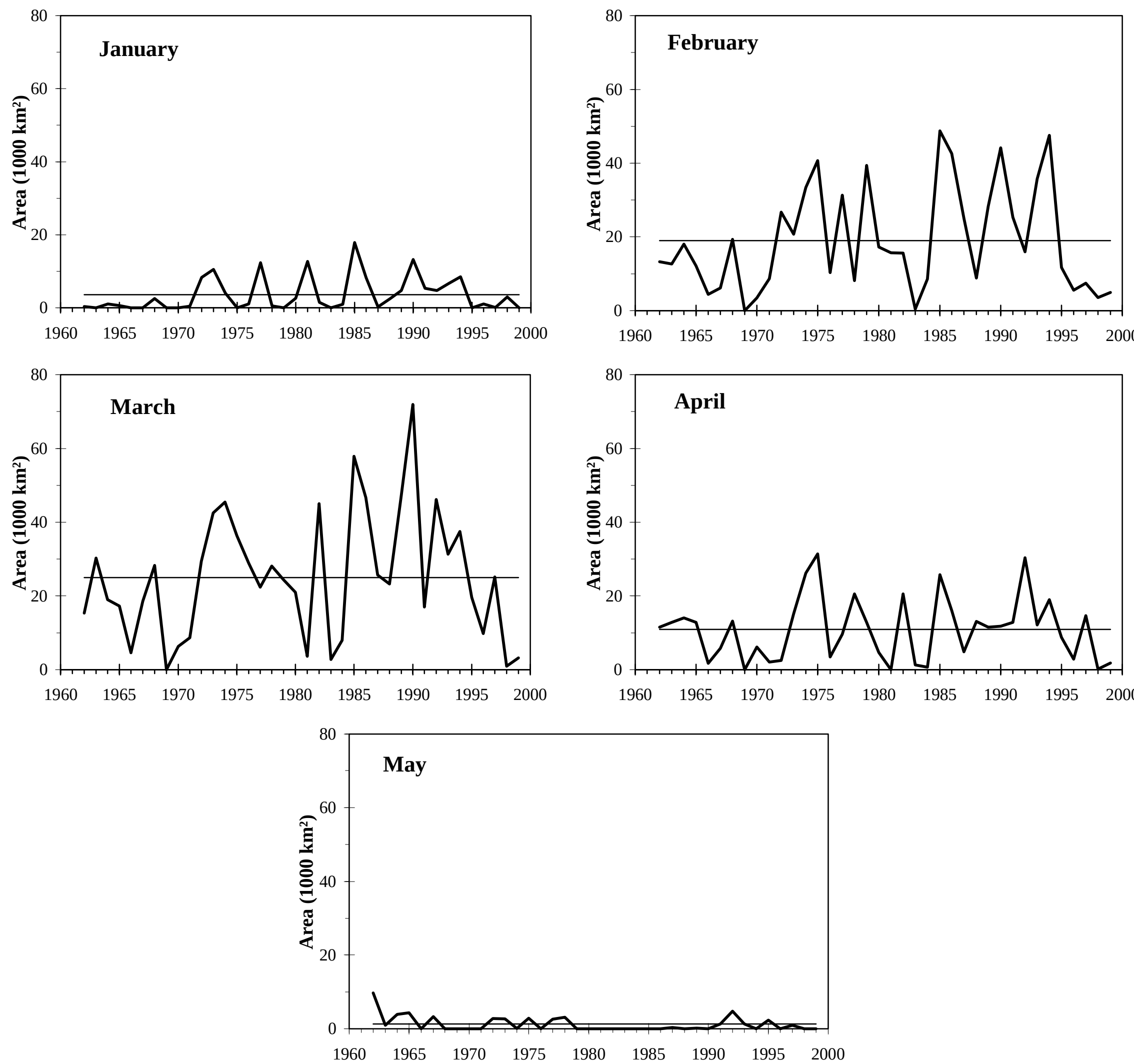


Fig. 16. The time series of ice area seaward of Cabot Strait, by month. The horizontal lines represent the long-term (1962-1990) monthly means.